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Resilience in the tantalum supply chain

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ABSTRACT

Tantalum, considered one of the critical elements by many countries, is a widely used metal in industries such as electronics, aerospace and automotive. The tantalum market has experienced several disruptions and subsequent price swings in the past, implying problems with its supply chain resilience and stability. In this study, we trace the entire value chain of the tantalum industry from mining to the intermediate and the downstream industries. Our interest is to see how dependent the tantalum supply chain is on specific countries and regions, how exposed primary production is to disruptions, and what mechanism counteracts disruption. This study assesses the tantalum supply chain from a resilience perspective rather than an investigation of any specific disruption in the system. We analyze several resilience-promoting mechanisms such as: (a) diversity of supply, (b) material substitution, (c) recycling and (d) stockpiling. We evaluate each of these mechanisms, and find that even though diversity of supply and stockpiling mechanisms have been decreasing for years, the tantalum supply chain has been flexible in its response to disruption. We find a much larger supply from unaccounted artisanal and small mining sources than expected based on official statistics, and estimate the unaccounted production in Africa, which shows an almost 250 percent increase from around 600 tons in 2004 to more than 2000 tons in 2014.. Besides flexible primary production from small-scale mining, we identfy rapid material substitution and increasing availability of waste and scrap as the main reasons behind the observed supply chain resilience.

1. Introduction

Tantalum, considered a critical element by many industrialized countries, is a widely used metal in industries such as electronics, aerospace, and automotive. The metal was discovered in 1802, a year after the discovery of niobium (Nb). Both metals share similar chemical properties and the ore is commonly referred either as columbite or tantalite (TIC, 2016a). Relative to any of the "major" metals such as copper, iron, or nickel, its annual production is minute. However, because it is produced in countries like The Democratic Republic of the Congo (DRC) and other parts of Africa where mining has financed rebel movements, tantalum is classified as a conflict mineral (Nest, 2011), along with tin (Sn), gold (Au) and tungsten (W).

Our interest is to see how dependent the tantalum supply chain is on specific countries and regions, how exposed primary production is to disruptions, and what mechanism counteract disruption. This study assesses the tantalum supply chain from a resilience perspective rather than an investigation of any specific disruption in the system. We aimed to analyze several resilience-promoting mechanisms such as: (a) diversity of supply, (b) material substitution, (c) recycling and (d) stockpiling.

In the past decades, the tantalum market has experienced disruptions and significant price swings, which imply problems with its supply chain resilience and stability. The metal therefore makes an interesting case study on the resilience of metals supply chains, especially in light of a previous study on the resilience of the supply chain of rare earth elements (REEs) that focused on neodymium magnets (Sprecher et al., 2015, 2017). One of the main findings of that study was that disruptions caused by export constraints put in place by the main producer of REEs (China) gave rise to significant illegal mining and exports that eventually contributed up to 40 percent of total world production. The authors speculated that the relatively novel phenomenon of illegal mining and smuggling actually helped increase the resilience of the REEs supply chain (since it allowed for an alternative method of obtaining raw materials when official production was constrained). However, because of its inherently opaque nature, they believed it

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would, in all likelihood, have detrimental effects on long term supply chain resilience.

Illegal mining and smuggling have been an unfortunate fixture of the tantalum supply chain for decades. Recently, Deetman et al. (2017) employed substance flow analysis (SFA) to estimate the European consumption of tantalum and found that the total quantity of tantalum consumed by Europe alone in a single year is higher than the reported global production of tantalum. Furthermore, and confirming earlier findings of Bleischwitz et al. (2012), global consumption of tantalum and tantalum-containing products do not match the production statistics of either the USGS (US Geological Survey) or the TIC (Tantalum-Niobium International Study Center). It seems likely that these agencies count only primary mine production and government authorized artisanal and small-scale mining (ASM). Thus, the data neglect the large quantity of tantalum from unauthorized, semi-illegal mining operations in Africa and associated illegal trade that feeds into the global market.

ASM extraction from soft alluvial deposits and semi-pegmatite ores is easy to mine and does not require significant capital investment. Informal sources have profound effects on tantalum prices and the sustainability of the industry, affecting the operations of established large scale mining (LSM) companies in Australia, Canada, Brazil, and elsewhere. ASM production at hundreds of sites also responds rapidly to price fluctuations compared to LSM mining, which require significant capitalization and years to start-up.

The popularity of resilience as a scientific framework stems from its application in ecology, where it is used to analyze the ability of a natural ecosystem to either resist or recover from disruptions (Holling, 1996). This ecology-based definition of resilience forms the basis of resilience work in the fields of information and communication sciences (Laprie, 2008) and manufacturing supply chain resilience (Zhang and Van Luttervelt, 2011). As reviewed by Wang et al. (2016), most of the studies dealing with supply chain resilience have concentrated on the abrupt disruptions in the supply chains of firms or products. These types of studies address financial or commercial risks arising from poor quality or sub-optimal supply chains and follow a qualitative methodology, or use a quantitative simulation-based framework that incorporates concepts of resilience into the process of supply chain design (Craighead et al., 2007; Huang et al., 2007; Sheffi and Rice, 2005; Christopher and Peck, 2004). Many of these studies deal with resilience either from a perspective of mitigation or response measures.

The concept of a resilient supply chain has also been integrated with the traditionally used concept of risk assessment of the supply chain of individual firms (Peck, 2003). Studies assessing the criticality of minerals have often used supply risk as a quantifiable concept (European Commission, 2014; US DoE, 2011). Previous academic work has assessed supply risk of various minerals from different angles: geological availability (Machacek and Kalvig, 2016), geo-political availability (Mancheri et al., 2013; Habib et al., 2016), economic importance (Mancheri, 2015; Mancheri, 2012; Graedel et al., 2015) and sustainability (Bailey et al., 2017). A common criticism of these concepts is that they are static in nature. This makes sense for geological availability, but less so for societal indicators such as geo-political availability and economic importance. In a review of material criticality studies, Dewulf et al. (2016) suggested that resilience become a core component of future material criticality analyses, precisely because resilience inherently takes a dynamic (i.e., time-dependent) approach.

Tantalum is mined both as a primary product and as a byproduct from tin, niobium, and lithium extraction. Of the more than 70 identified tantalum-containing minerals, tantalite $(Fe,Mn)(Ta,Nb)_2O_6]$, microlite $[(Na,Ca)Ta_2O_6 (O,OH,F)]$, and wodginite $[(Ta,Nb,Sn,Mn,Fe)O_2]$ are of greatest economic significance (USGS, 2014a). Tantalum ore is composed of both tantalum and non-tantalum containing minerals, and the Ta_2O_5-equivalent content is typically 0.02–0.04 percent. Low-grade tantalum ore is physically concentrated (beneficiation) to a concentrate of 20–40 percent Ta_2O_5-equivalent at the mining site before sale to smelters (Linnen et al., 2014). Tantalum minerals are priced according to Ta_2O_5-equivalent content.

Even though production of tantalum is minute compared to base metals, its reserves are not. Reserves are defined as the resources that could be economically extracted or produced. However, the term 'reserves' does not necessarily signify that extraction facilities are in place and extraction is economically viable (King, 2011).. The tantalum content of each deposit is essential in estimating the deposit's profitability. According to USGS estimates, Brazil and Australia have the largest reserves, holding more than 85 percent of the global reserves and other reserves are in Canada and African nations. Estimates of the most likely resource base by the TIC show that about 40 percent is situated in South America and about 21 percent in Australia. Tantalum is also produced in Brazil, Malaysia, and Thailand from "tin slag," a by-product of tin smelting. Tantalum raw materials are also being explored in Canada, Colombia, Egypt, Madagascar, Namibia, Saudi Arabia, Sierra Leone, South Africa, Tanzania, Venezuela, and Zimbabwe. Estimated global reserves of tantalum are large and more than sufficient to meet global demand for the foreseeable future, possibly the next 500 years. Therefore, geological availability does not appear to be a major concern for the supply of tantalum.

As of 2017, there are only a handful of countries producing tantalum ore but there are very large differences in production quantities among these countries. Australia used to be the largest producer, but its share declined drastically after the main producing mine closed in 2008. Brazil is a major primary mine producer while large quantities are produced in the DRC, Rwanda, and other African countries by artisanal miners. Additional quantities are produced intermittently or at low levels in Australia, Burundi, Malaysia, Mozambique, Namibia, Nigeria, Thailand, and Zimbabwe (USGS, 2016).

ASM operations greatly contribute to the opaque and even secretive nature of the tantalum industry. Although recent legislation and guidelines have pushed buyers to ensure purchased mineral is conflict free, it appears a large share of unaccounted supply still emerges from Central African countries. The quantity of production does not match either the tantalum contained in intermediate and final products, nor does it correspond to the resource base and global reserves, as most of these proven resources are concentrated in well-developed markets rather than in African countries (Fig. 1). There have been attempts – both governmental and non-governmental – to prevent trade in conflict minerals including tantalum (Young, 2015; Bleischwitz et al., 2012). One such major initiative is section 1502 of the Dodd-Frank Act, which essentially requires US companies to report to the US Securities and Exchange Commission (SEC) and disclose whether the tantalum or other conflict minerals they buy originate in a conflict region (SEC, 2011). A similar law was introduced in the EU parliament in June 2016 (EU Parliament, 2016) and expected to be implemented by 2021.

Tantalum concentrate is mainly processed by smelters in industrialized countries such as China, Japan, Germany, and the USA. Ta_2O_5 concentrate is dissolved in acid at high temperatures to extract K-salt (potassium fluortantalate, potassium fluorotantalate, potassium heptafluorotantalate, or potassium tantalum fluoride) or purified into Ta_2O_5 (tantalum pentoxide or tantalum oxide). Further processing results in tantalum metal powder and other tantalum-containing materials (TIC, 2016a).

Fig. 2 shows the number of major processing companies in different countries. China tops the list with 16 smelting companies. These numbers may not be completely accurate as during our investigation we found a number of small scale companies who process tantalum in China, Korea, Kazakhstan, and the US and they are not listed in the figure. A study by Achebe identified a total of 48 smelting and refining facilities worldwide, with China hosting 19, the US and Mexico 11 facilities each, Europe having 8 facilities, and Eurasia, including Japan, India, Thailand, Kazakhstan, and Russia hosting 8 facilities (Achebe, 2016).

Disruptions in the tantalum supply chain have occurred during the transportation of the beneficiated concentrate from mining countries to